Jet Propulsion Laboratory
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Mars Reconnaissance Orbiter Maneuver Plan for Mars 2020 Entry, Descent, and Landing Support and Beyond

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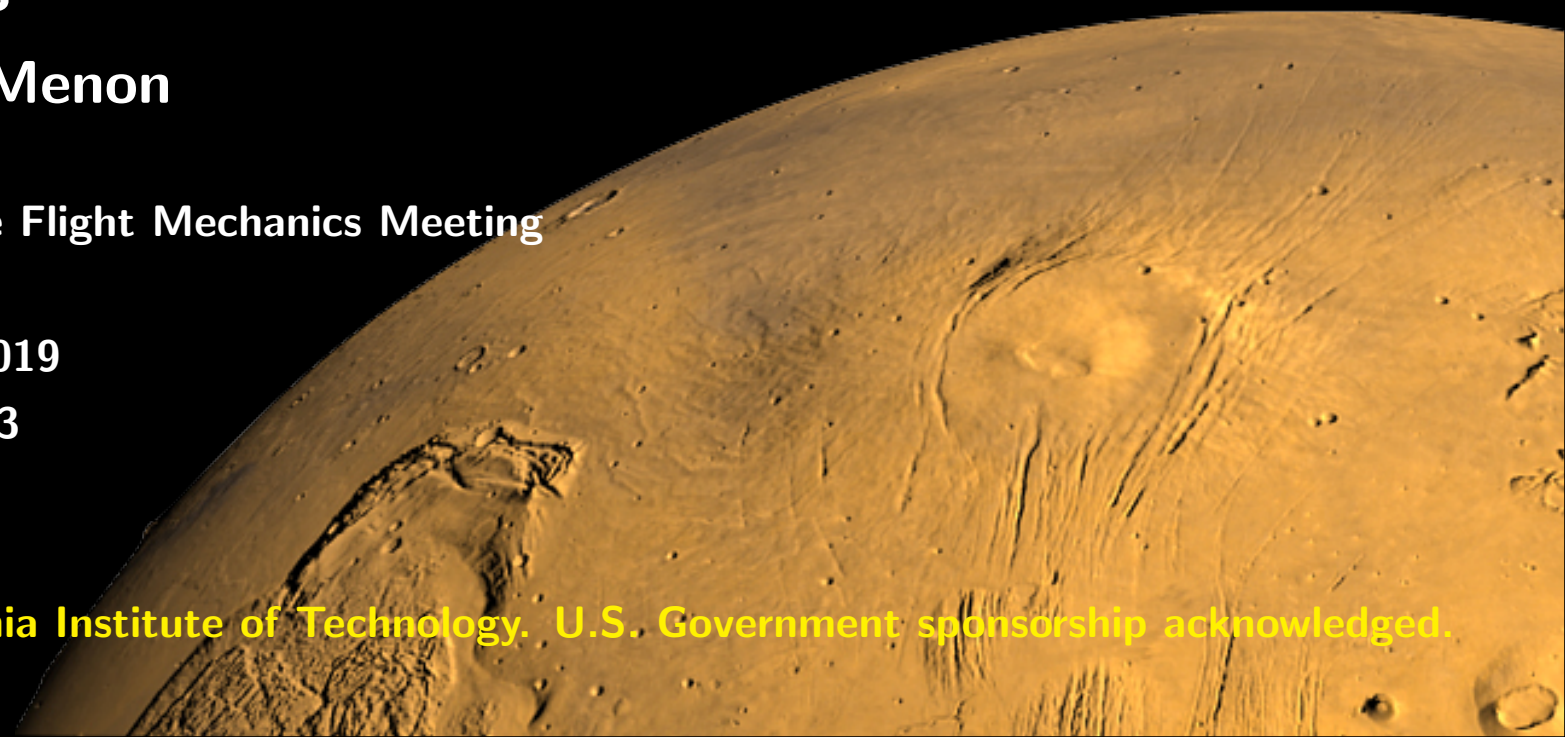
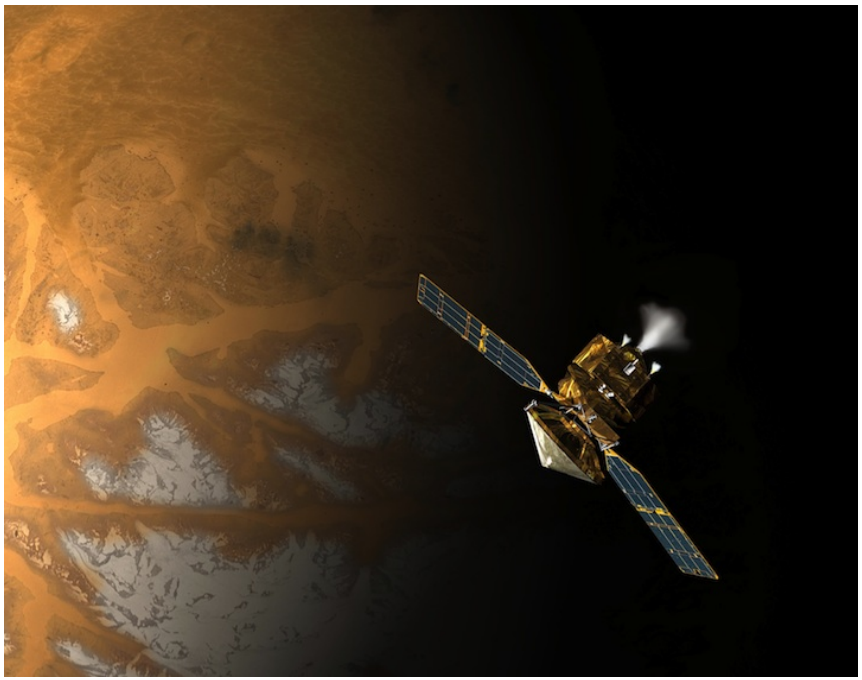


Mars Reconnaissance Orbiter Project

Mars Reconnaissance Orbiter Mission

The Mars Reconnaissance Orbiter launched on August 12, 2005 from the Cape Canaveral Air Force Station and arrived at Mars on March 10, 2006. After aerobraking, MRO began the Primary Science Phase (PSP) in November 2006 and continues to perform science observations at Mars.



MRO Spacecraft:

- **Spacecraft Bus:** 3-axis stabilized ACS system; 3-meter diameter High Gain Antenna; hydrazine propulsion system
- **Instrument Suite:** HiRISE Camera, CRISM Imaging Spectrometer, Mars Climate Sounder, Mars Color Imager, Context Camera, Shallow Subsurface Radar, Electra Proximity Link Payload (among other instrument payloads)

MRO Primary Science Orbit (PSO)

The MRO PSO is designed to satisfy science and mission requirements; the spacecraft is flown in an orbit designed to optimize the science instruments performance. The MRO PSO is defined by three key characteristics:

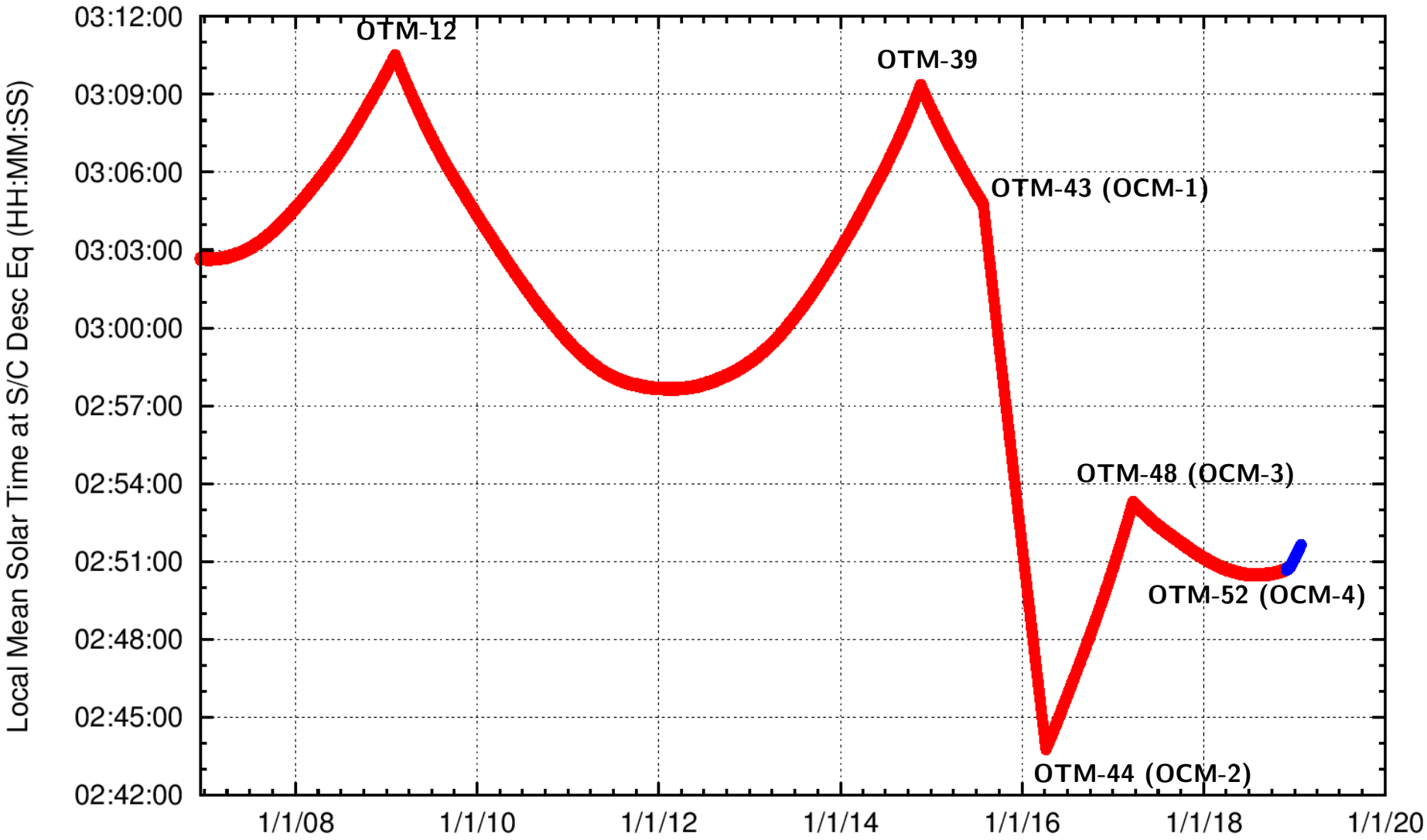
- **Sun-synchronous** orbit ascending node at 3:00 PM $\pm$ 15 minutes Local Mean Solar Time (LMST) (daylight equatorial crossing)
- Periapsis is **frozen** about the Mars South Pole
- **Near-repeat ground track walk (GTW)** every 17-day, 211 orbit (short-term repeat) MRO targeting cycle, exact repeat after 4602 orbits. The nominal GTW is 32.45811 km West each 211 orbit cycle (maintained within $\pm$ 40 km)

Local True Solar Time (LTST) is also required to remain between 2 PM and 4 PM

MRO Propulsive Maneuvers

- MRO nominally implements a propulsive maneuver in one of two standard maneuver orientations:
  - **in-plane** ($\pm$spacecraft velocity vector) or
  - **out-of-plane** ($\pm$spacecraft angular momentum vector)
  - Typical PSO maintenance maneuvers (Orbit Trim Maneuvers, or OTMs) are for apses height control; most have been performed at orbit periapsis to raise orbit apoapsis. These maneuvers are used to maintain the PSO GTW
- Orbit LMST control (inclination change) is achieved via out-of-plane maneuvers, referred to as **Orbit Change Maneuvers (OCMs)**
- Orbit phasing is achieved via in-plane maneuvers, referred to as **Orbit Synchronization Maneuvers (OSMs)**

Local Solar Time Profile (February 2007 – December 2018)



Past Combined Out-of-Plane and In-Plane Maneuvers

Maneuver	Maneuver Epoch (UTC-SCET)	Node	Independent ΔVs ΔV_{Out} (m/s)	Independent ΔVs ΔV_{In} (m/s)	Combined ΔV (m/s)	Ind. ΔVs − Comb. ΔV (m/s)	LMST Target
OTM-12	04-Feb-2009 17:55:27	DEqX	3.2000	0.0610	3.2006	0.0604	3:00 PM PSO Maintenance
OTM-39	19-Nov-2014 13:21:44	DEqX	3.3000	1.0124	3.4518	0.8606	3:00 PM PSO Maintenance
OTM-43 (OCM-1)	29-Jul-2015 13:21:31	DEqX	5.3300	0.0910	5.3308	0.0902	2:30 PM @ InSight 2016 EDL
OTM-44 (OCM-2)	06-Apr-2016 13:31:09	AEqX	7.9000	0.4760	7.9143	0.4617	3:00 PM PSO Maintenance
OTM-48 (OCM-3)	22-Mar-2017 13:38:40	DEqX	3.1700	0.4120	3.1967	0.3853	2:52 PM @ InSight 2018 EDL
OTM-52 (OCM-4)	12-Dec-2018 14:18:23	DEqX	1.2000	0.7270	1.4030	0.5240	3:15 PM @ Mars 2020 EDL
						2.3822 m/s savings	

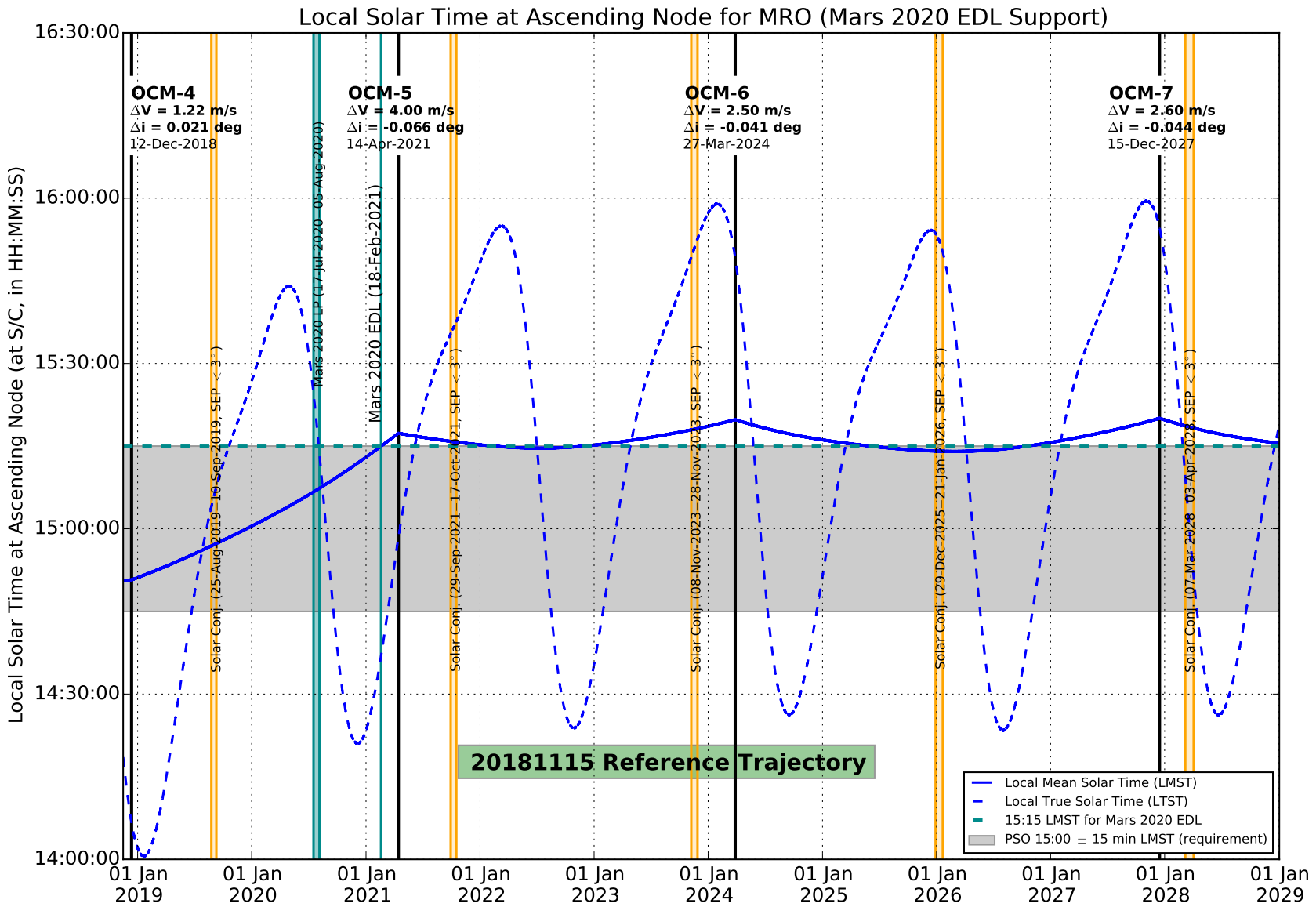
- OTM-52 (OCM-4) was performed on Dec. 12, 2018 to change nodal drift such that 3:15 PM LMST at Mars 2020 EDL will be achieved
  - Estimated LMST at Mars 2020 EDL after OTM-52 was ∼3:13:20 PM
  - Minimum LTST following OTM-52 on January 18, 2019 and estimated to be ∼2:00:25 PM
  - OTM-52 also used to remove a large ∼213 km GTW repeat error that had built up since InSight EDL phasing began

OCM Strategy for Mars 2020 EDL and Beyond

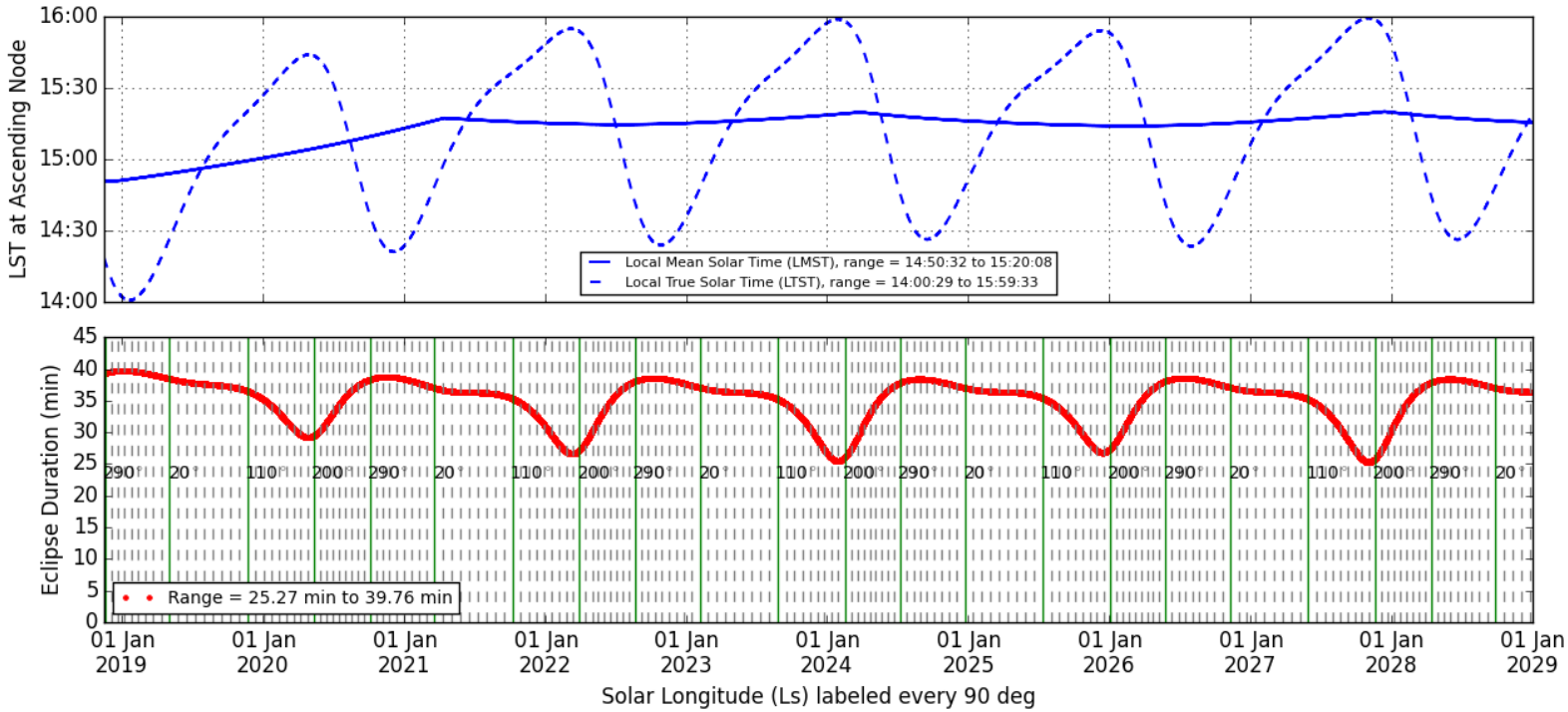
Maneuver	Maneuver Epoch (UTC-SCET)	ΔV (m/s)	Prop. Usage (kg)	Inc. Change (deg)	LMST at Time of OCM	Comments
OCM-4	12-Dec-2018 14:19:49	1.22	0.66	0.021	2:50:46 PM	Achieve 3:15 PM LMST for Mars 2020 EDL
OCM-5	14-Apr-2021 13:26:58	4.00	2.17	−0.066	3:17:24 PM	Maintain near 3:15 PM LMST through Mar. 2024
OCM-6	27-Mar-2024 13:50:35	2.50	1.36	−0.041	3:19:46 PM	Maintain near 3:15 PM LMST through Dec. 2027
OCM-7	15-Dec-2027 13:43:57	2.60	1.41	−0.044	3:20:05 PM	Maintain near 3:15 PM LMST beyond 2028
	Total	**10.32**	**5.60**			

- OCM-4 was designed to change the nodal drift such that the 3:15 PM LMST requirement at Mars 2020 EDL will be achieved
- OCMs 5–7 were designed such that the LMST varies by only up to 5 minutes from 3:15 PM and LTST remains between operational limits of 2 PM and 4 PM

Local Solar Time Profile for Mars 2020 EDL Support

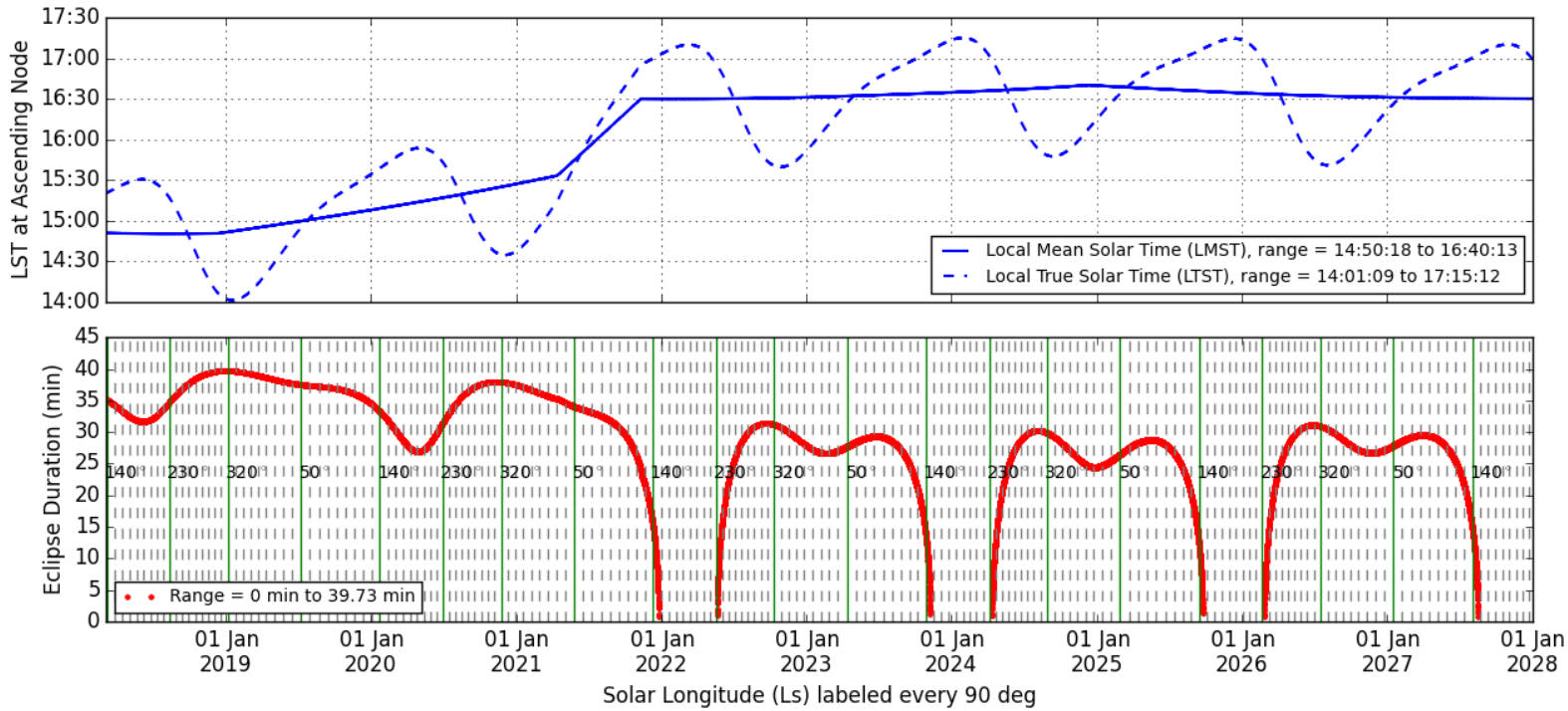


Sun Eclipse Durations w/ Orbit Maintained at 3:15 PM LMST



- Sun eclipse durations as a function of solar longitude (L_s) through end of reference trajectory, representing approximately five Mars years
- Following OCM-5 in April 2021, the LMST is maintained near 3:15 PM
- Maximum eclipse durations range between ∼25 min and ∼40 min during reference trajectory span

Sun Eclipse Durations w/ Orbit Maintained at 4:30 PM LMST (Prior Plan)



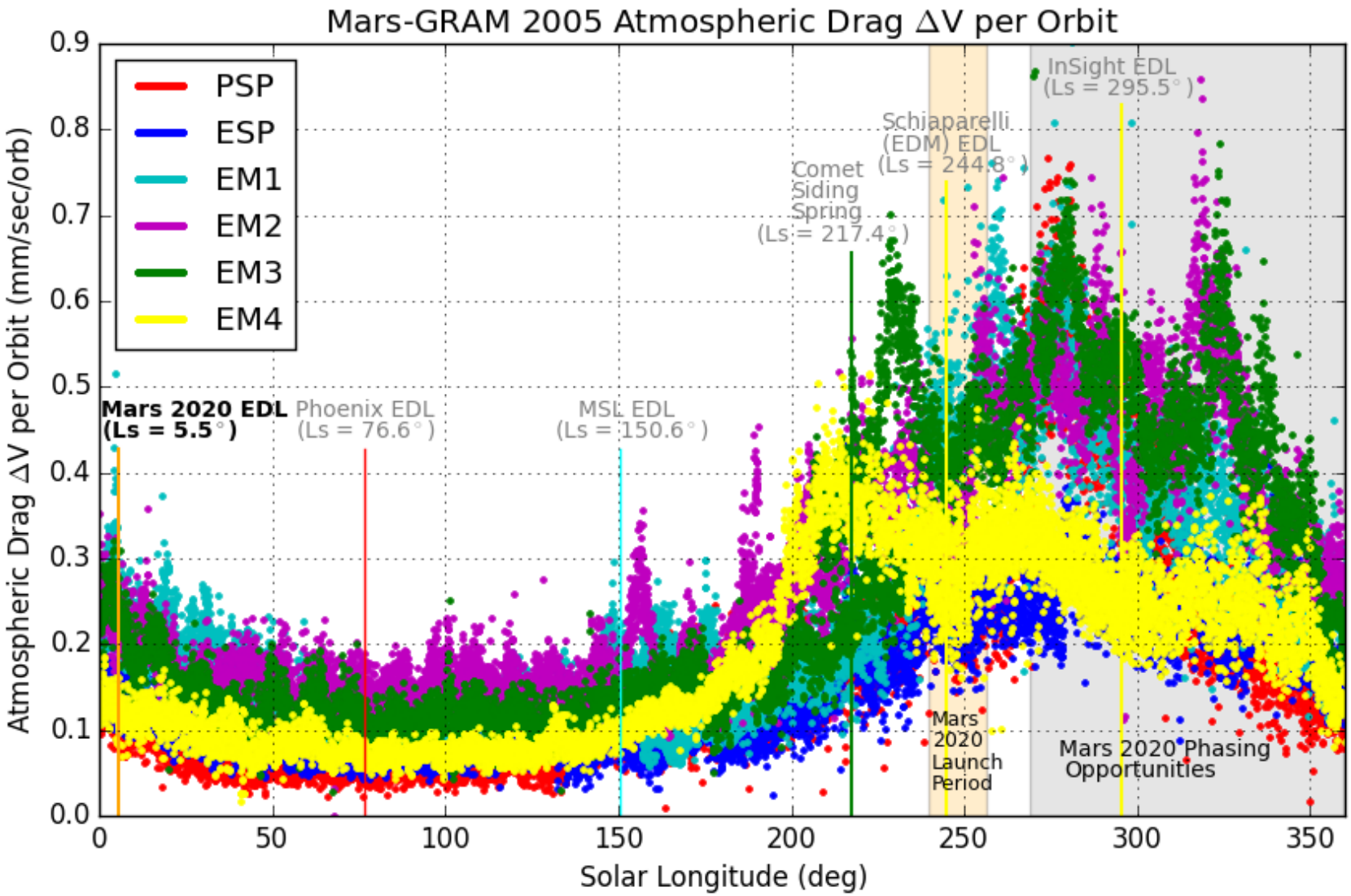
- A battery anomaly was detected following OTM-49 execution on Sept. 13, 2017
  - Reducing eclipse durations identified as possible action to improve battery capacity
  - To decrease time MRO spends in eclipse, previous plan was to move MRO to 4:30 PM LMST after supporting Mars 2020 EDL (following OCM-6 in Nov. 2021)
- Starting in 2022 eclipses no longer occur at L_s near 180° and maximum eclipse durations reduce from ∼40 min (current PSO orbit) to ∼31 min
- This was one of the options to address MRO's battery concerns as MRO continues its battery charging strategy — a similar plan to move to 4:30 PM LMST could still be under consideration

Conclusion

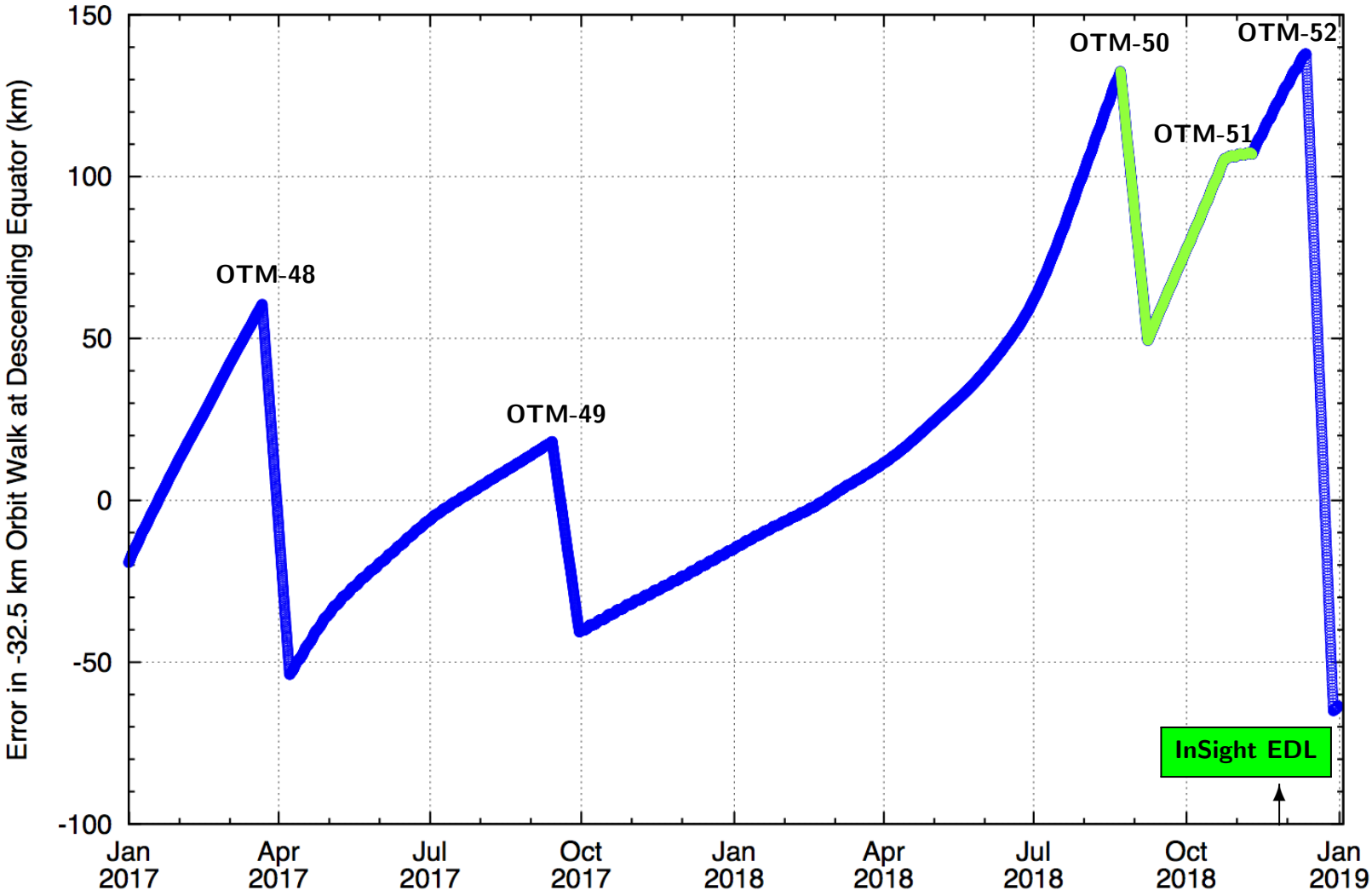
- MRO Navigation Team has successfully supported science operations and relay for landed missions at Mars for nearly 12 years through the implementation of more than 50 propulsive maneuvers
  - Maneuvers controlled GTW errors within mission requirements while maintaining the frozen condition of the science orbit
  - Maneuvers satisfied LMST requirements for PSO as well as EDL sequences of incoming missions such as InSight on Nov. 26, 2018
- As of December 2018, MRO still has a generous margin of $\sim$194 kg of usable fuel, which translates to nearly 400 m/s of remaining ΔV
- MRO will support Mars 2020 mission in February 2021 and maintain MRO's orbit near 3:15 PM LMST for science operations thereafter
  - Deterministic cost of $\sim$10 m/s (small percentage of available ΔV)
  - First part of maneuver plan was implemented with OTM-52 on December 12, 2018 to move to 3:15 PM LMST for Mars 2020 EDL
- Mars Exploration Program Office expects MRO to continue providing relay support through 2028
- Proposed maneuver plan will help ensure this expectation is met while preserving MRO's primary science operations at Mars

Backup Slides

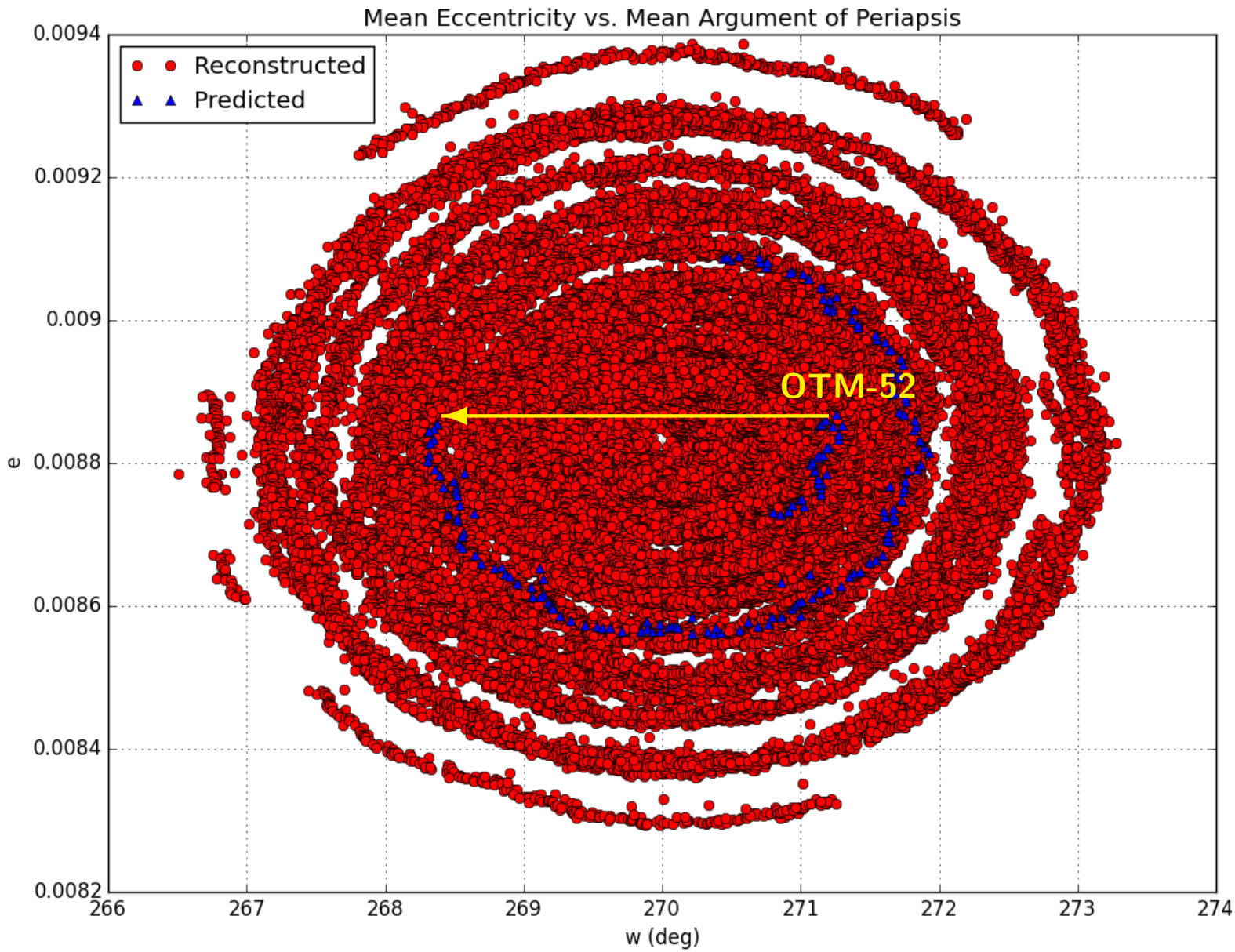
Atmospheric Drag ΔV Experienced by MRO



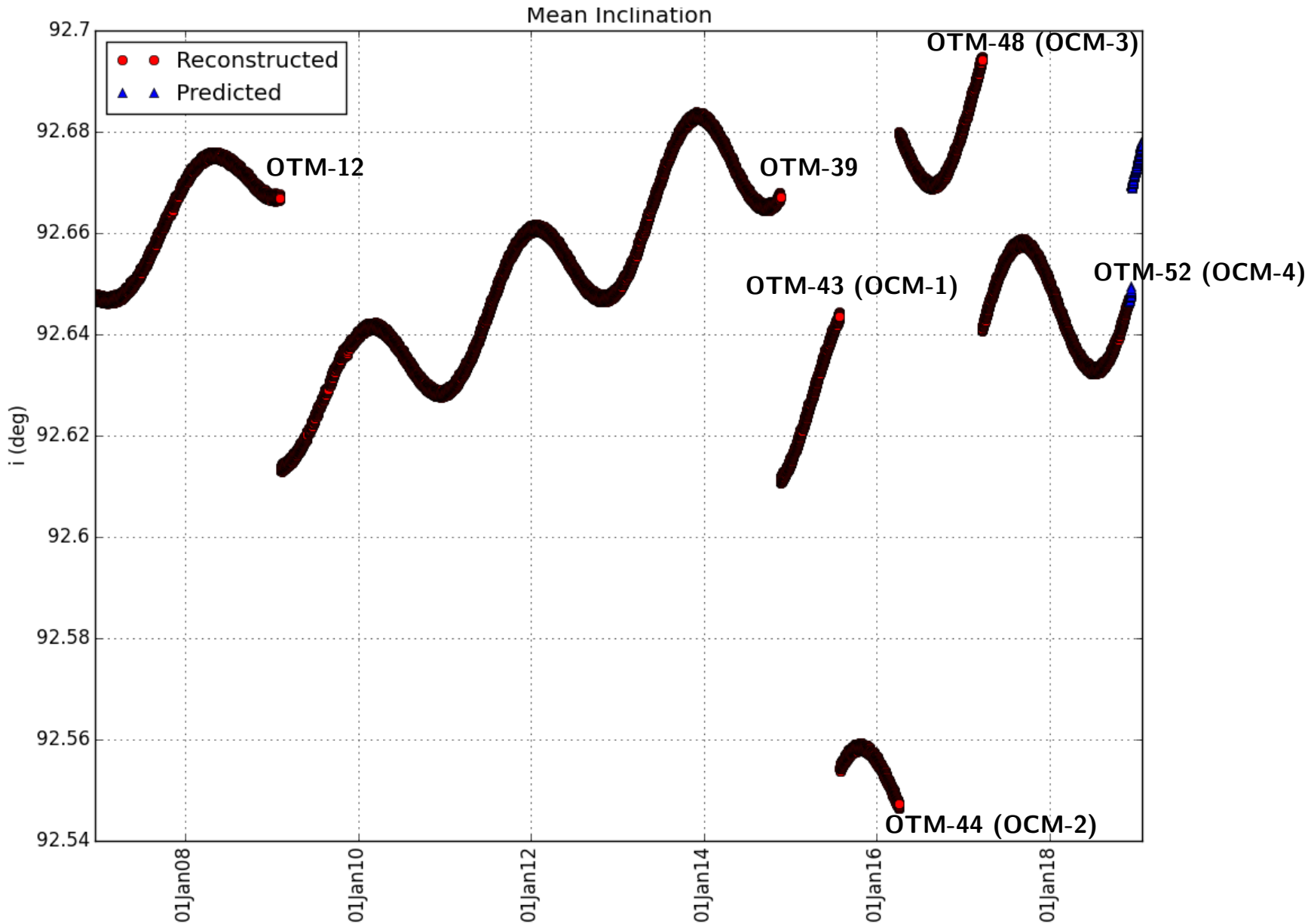
Ground Track Walk Error (January 2017 – December 2018)



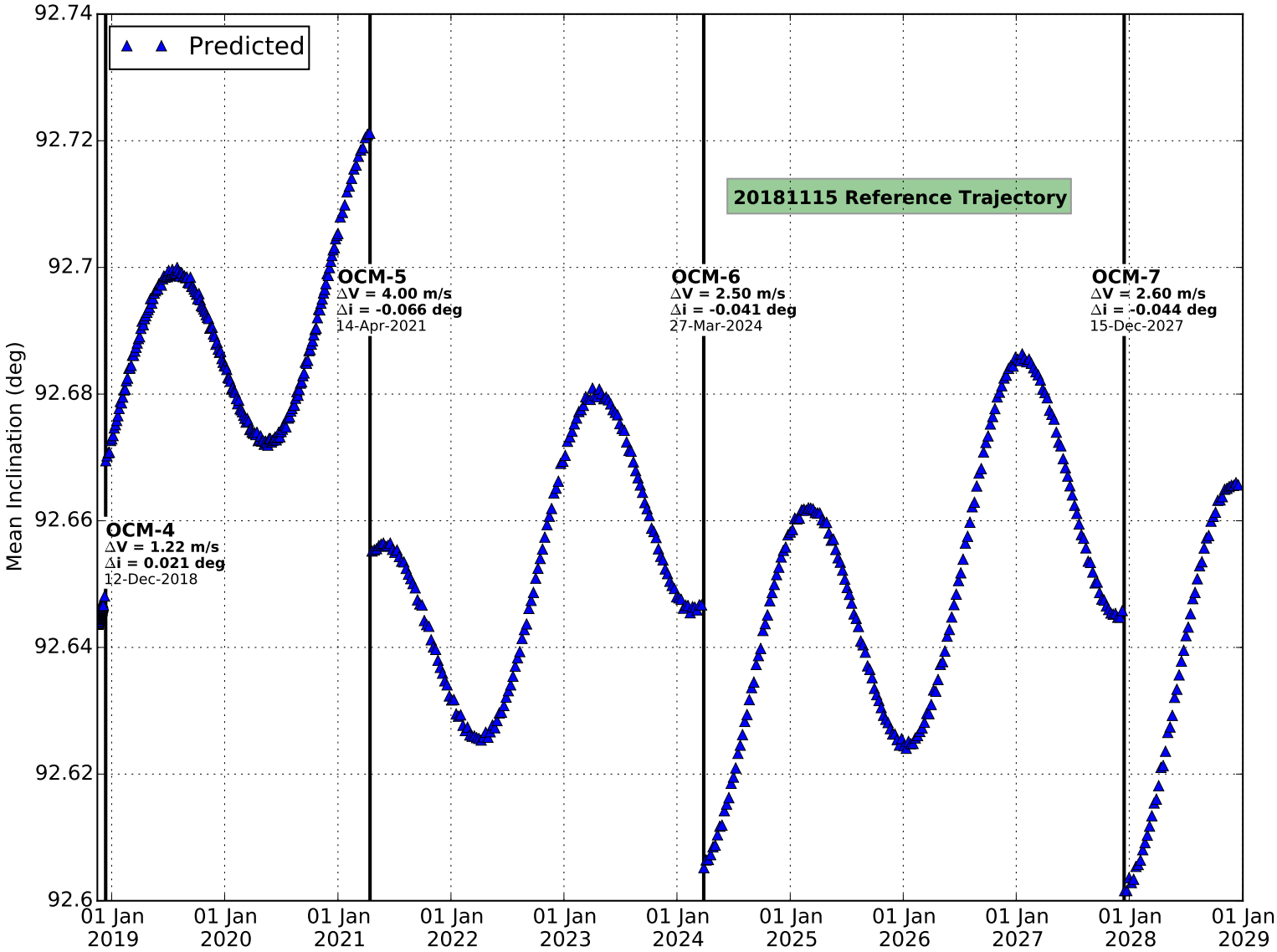
2007-2018 Reconstructed Mean $e - w$ (Frozen about Mars South Pole)



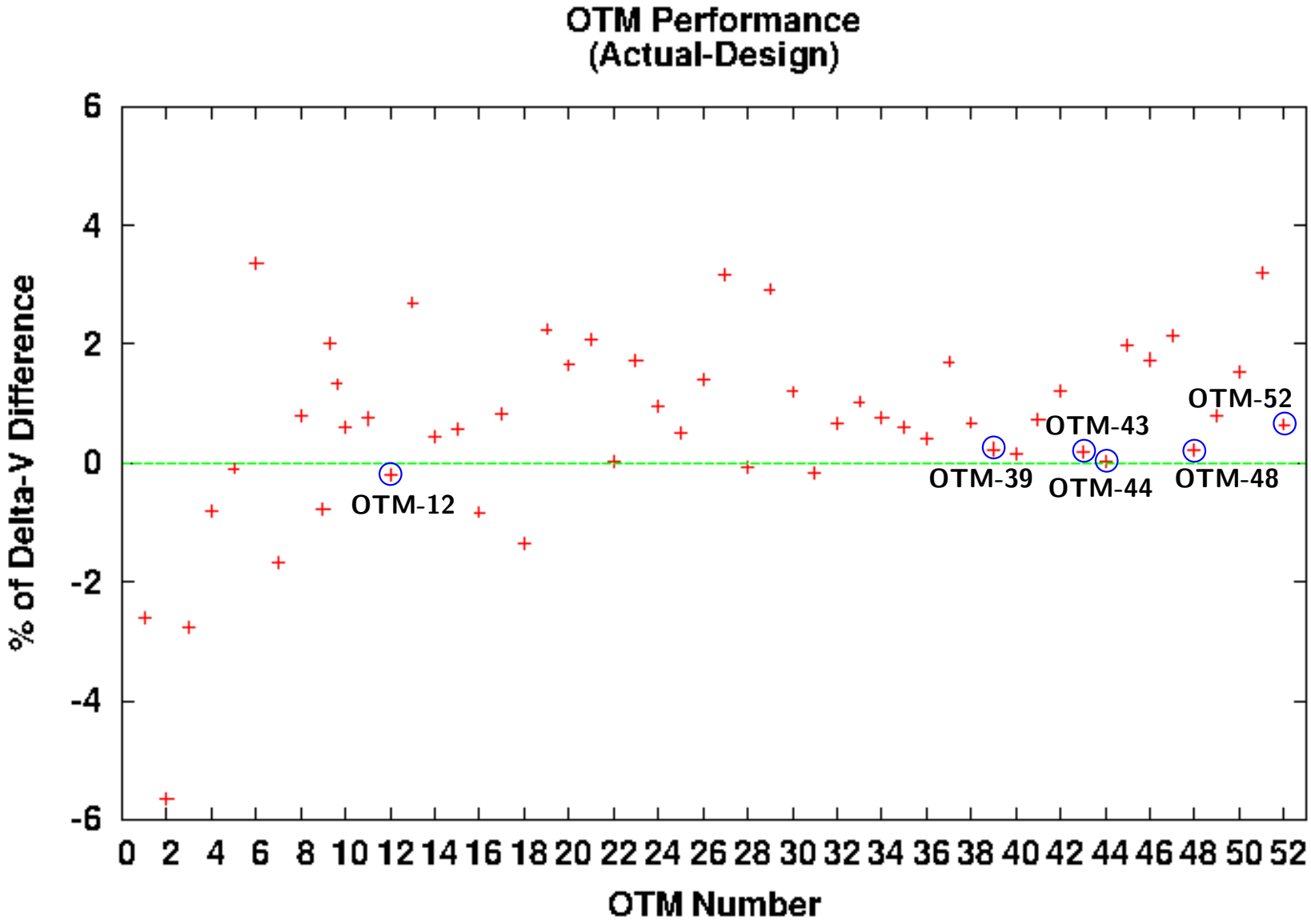
Mean Inclination (February 2007 – December 2018)

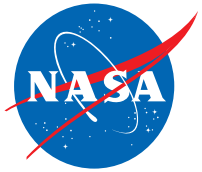


Mean Inclination Profile for Mars 2020 EDL Support



Maneuver Performance (February 2007 – December 2018)





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